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FINAL REPORT

Contract NASw-2660

Observation of Soft X-Rays From Cosmic Sources

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INTRODUCTION

The purpose of this program was to continue the investigation of spectra and angular structure of soft x-ray sources which was begun under Contracts NASw-1388 and NASw-2414. The rocket payload flown on NASA-17.012 was refurbished, modified, and flown on 17.013 under this contract.

During the flight of Aerobee 17.013 observations were made on a binary x-ray source, an extended extragalactic x-ray source and several nearby stars were surveyed for x-ray emission. These observations and their objectives are discussed in the following paragraphs.

The energy spectrum and time structure of x-ray flux from the binary source, Her X-1, was investigated in the range from 0.15 to 6 keV. This source was observed at a binary phase of 0.18 with the system near elongation normal to the line of sight. Intense pulsations have been observed in optical emission lines near this binary phase. The purpose of the rocket observations is to confirm the soft x-ray flux reported by the Naval Research Laboratory and investigate its intensity and pulsation phase relative to flux at higher energies. These observations were made at a different binary phase than those of NRL, in particular, at a phase when line of sight x-ray absorption is likely to be a minimum.

The spectrum and angular distribution of x-ray emission from the x-ray source in the Virgo Cluster of Galaxies, near M 87, was also observed. This measurement was made with greatly improved sensitivity resulting from longer

observing time with a detector of lower background than that used for the observation of this source during the flight of 17.08. The purpose of the observation is to investigate the angular structure of this source, now in dispute, and study the relationship between the x-ray emission, the active galaxy M 87, and the cluster of galaxies.

Several stars were observed for x-ray emission during a routine part of the ACS program when a star tracker "locks on" these stars to calibrate the gyro-system. These stars are α Leo, ζ Her, and ϵ Vir. A scan was also made over ϵ Aur, whose companion star may be a black hole, and α Aur. Evidence for x-ray emission from α Aur was obtained from previous observations with this payload on the flight of 17.012. The purpose of these observations is to investigate nearby stellar objects for x-ray emission, since there is increasing evidence that such objects may be transient sources of soft x-rays.

EXPERIMENT PAYLOAD

A major part of the instrumentation used for observations under this contract has been flown previously on NASA-Aerobees 17.08 and 17.012. A schematic view of the payload for 17.013 is shown in Figure 1. The primary instrumentation consists of a pair of gas flow proportional counters which view space through a set of x-ray reflectors. These reflectors are parabolic in shape along the lengths shown and are linear in a dimension normal to the plane of the figure. The surface of these mirrors is made from polished Kanigen, a form of chemically deposited nickel. In this view, a plane wave of x-rays entering from the left undergoes a single

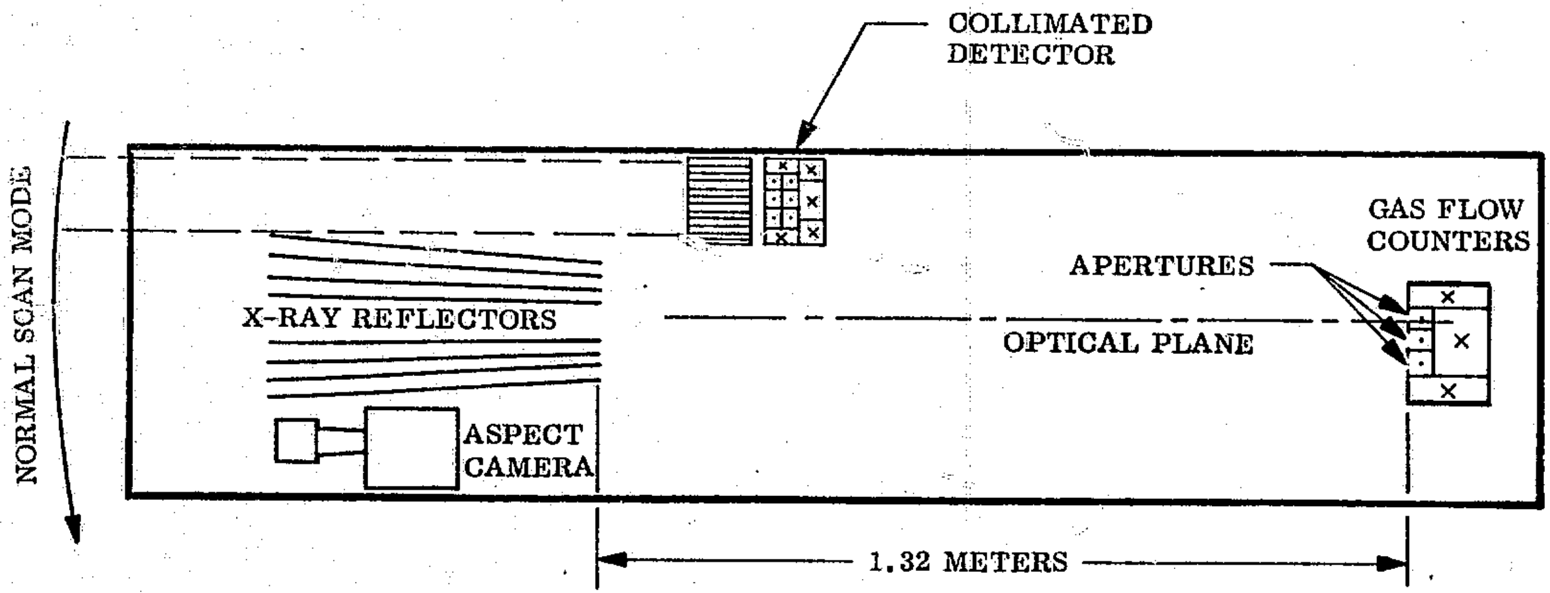


Fig. 1 A schematic view of the payload flown on Aerobee 17.013 CG.

reflection by the mirrors and is focussed on an aperture in the focal plane. Three apertures are used in this system, one which lies on the optical plane and two others which are slightly off this plane. The fields of view of these apertures, when projected through the reflector system onto the sky, are 0.1° by 8° for that on the optical plane and 0.25° by 8° for those which are off the plane. Behind each aperture is a gas flow proportional counter which detects the x-rays. The primary mode of acquiring data with this system is by slowly scanning these fields of view across an x-ray source and registering the counting rates in the detectors as the image of the source sweeps across the apertures. By utilizing rate-integrating gyros, the rocket attitude control system (ACS) was able to provide a stable scan rate of $.02^{\circ}$ $\sec^{-1}$ during data acquisition. The star tracker allows the ACS to position the start of a scan on the sky to within a few tenths of a degree. A 35 mm camera photographs the star field every 1.5 sec to provide aspect data.

Since the x-ray efficiency of the reflector system decreases rapidly at energies above 2 keV it was necessary to provide an auxiliary detector for observing the spectrum of Her X-1 at higher energies. For this purpose, a proportional counter with a 1 micron polypropylene window was added to the payload as shown in Figure 1. This detector has an area of approximately 100 cm^2 and has its field of view collimated to 2° FWHM in two dimensions. A gas anticoincidence system reduced the background rate in this proportional counter to 0.3 count $\sec^{-1}$ in the range from 0.75 to 6 keV as measured on the ground. Anticoincidence counters are indicated in Figure 1 by chambers with an X at their center.

In addition to the collimated proportional counter the payload from 17.012 was modified in the following ways for the flight of 17.013.

a) The proportional counter system at the reflector focus was redesigned to increase the angular interval over which x-rays were detected and to improve the anticoincidence efficiency for reducing background counting rates. The detector system on 17.012 had two proportional counters using different gases which were isolated by a pressure tight wall. These detectors had apertures which were 0.1° and 0.3° wide. In the new design the wall, its pressure seal, and the detector with a 0.3° aperture were replaced by two detectors, each having a 0.25° aperture. The time available for observing a source as it scans across the focal plane was thereby increased by ~ 50%. Background rejection efficiency was increased by surrounding the x-ray detectors as completely as possible with gas anticoincidence counters.

b) Previously, the proportional counters at the reflector focus operated at 400 Torr, requiring complicated gas flow systems because of the sub-atmospheric pressure. Also, because the detectors used different gases, two of these flow systems were required. Since reliability of gas flow systems and thin polypropylene windows operating at slightly above atmospheric pressure have greatly improved, this redundancy was no longer required. The system was redesigned for 17.013 so that the detectors used a common gas and operated at 760 Torr. Gas was flowed through the detectors until just before launch when they were sealed-off. During flight a demand-type regulator supplied gas to compensate for any pressure drop. This greatly simplified the gas system at a considerable saving in weight.

c) A 32-channel pulse height analyzer (PHA) was used to digitize the pulse amplitudes from the detectors at the reflector focus. Outputs from the three detectors were fed through a common amplifier into the PHA. Each x-ray pulse generated an eight bit word, where the first five bits were the digitized pulse amplitude and the remaining three bits identified the detector in which the event had occurred. For each event, this eight bit word was shifted to a register which was sampled approximately every 50 microseconds by a PCM encoder. Output of the encoder was transmitted to the ground for later de-coding. On 17.012 the data were transmitted in an analog manner. This system was retained on 17.013 for monitoring the detector operation in routine checks and for redundancy.

d) Fiducial markers placed on the camera photographs for calibration purposes were improved by replacing cross-shaped apertures in front of light emitting diodes with precise circular apertures .006" in diameter.

e) Detector energy calibration with a radioactive source was initiated just before each slow data taking scan in addition to the beginning and end of the flight.

f) The Bragg crystal spectrometer and a photoelectric aspect sensor flown on 17.012 were not flown on 17.013.

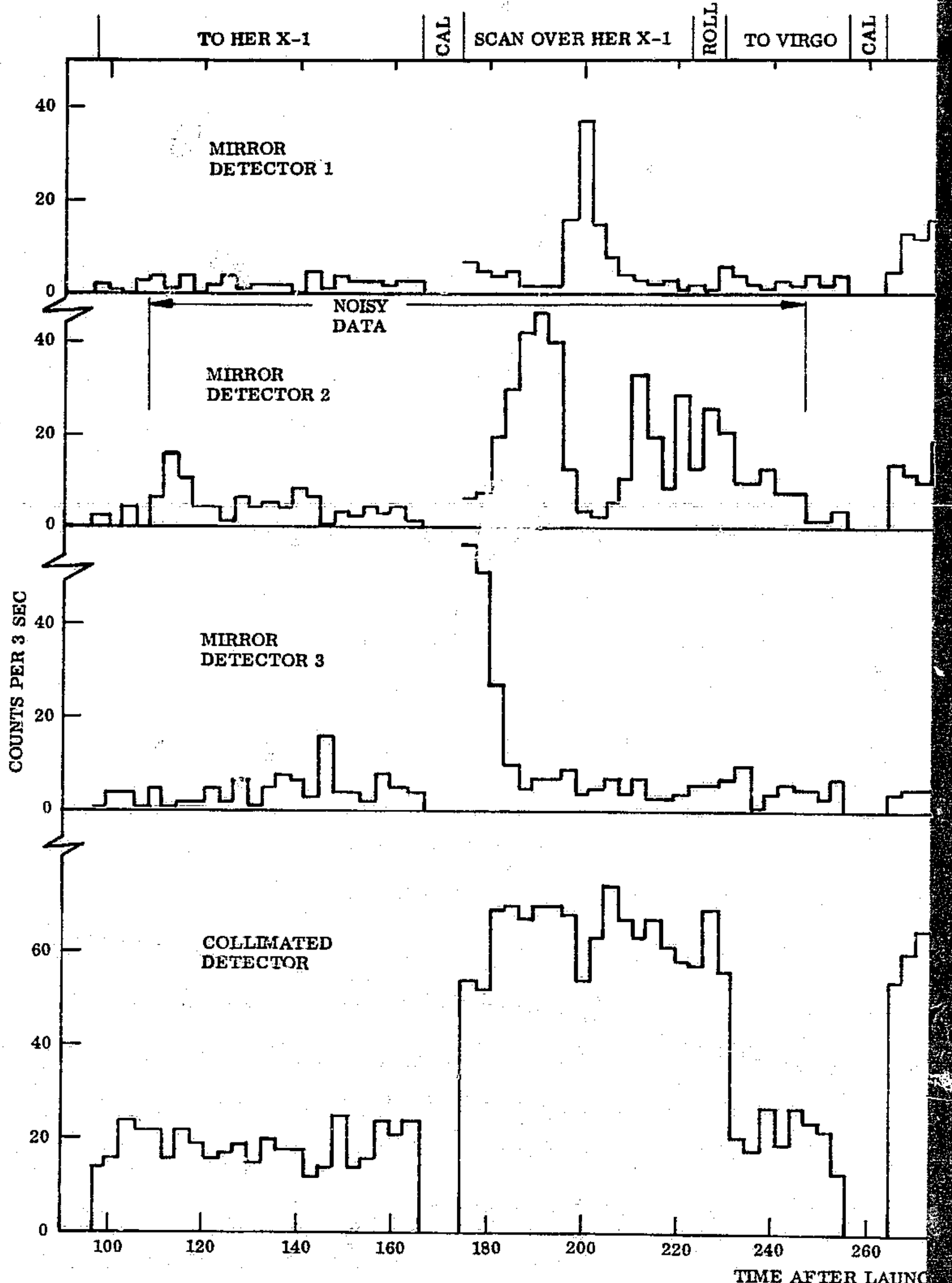
PRELIMINARY RESULTS FROM 17.013

Aerobee 17.013CG was successfully launched from White Sands Missile Range on 3 February 1975 at 02:16 MST. The payload reached a peak altitude of 253 km and provided a time above 120 km of 342 sec. All of the instruments in the experiment payload performed properly and acquired useful data.

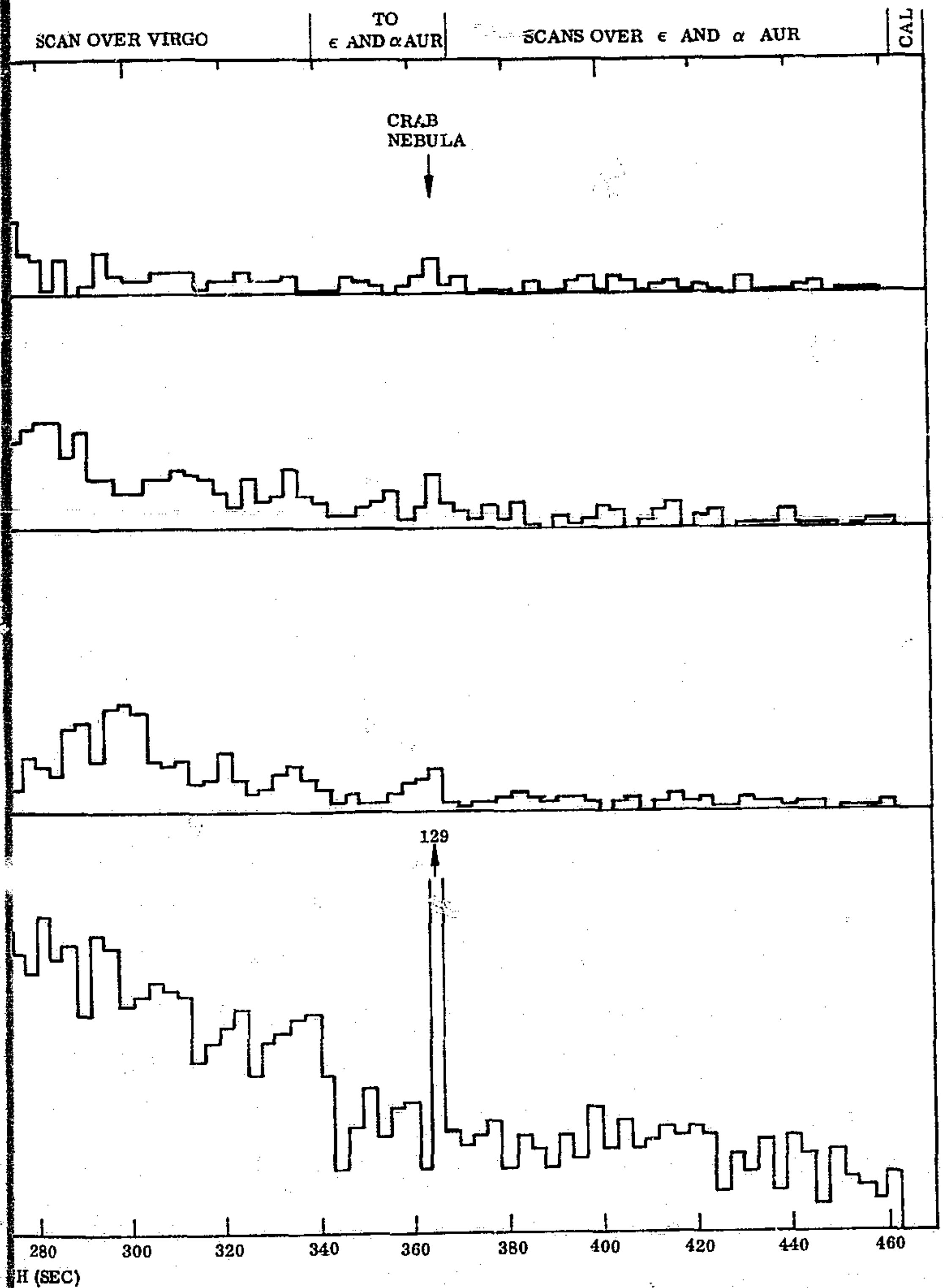
Preliminary data from the three detectors at the focus of the x-ray mirror and from the collimated proportional counter are shown for the entire flight in Figure 2 on the following page. Detector 1 is behind the 0.1° aperture while detectors 2 and 3 are behind 0.25° apertures. The counting rates in each of the detectors have been summed for 3 sec intervals and plotted as histograms. The mirror detector data refer to the energy range from .5 to 2 keV, while those from the collimated detector range from .75 to 6 keV.

The sequence events which occurred during the flight are indicated along the top of the figure. Labels such as "to Her X-1" indicate a sequence of attitude control system (ACS) maneuvers required to position the payload axis for data taking scans and "Cal" indicates the duration of a period of energy calibration of the detectors with a radioactive source. Data have not been included for the "Cal" periods. A period of "noisy data" is indicated in the plot for mirror detector 2 when the analog data output malfunctioned briefly. The PCM data appears to be clean and does not have this difficulty.

FOLDOUT FRAME 1



FOLDOUT FRAME 2



A 1.0° scan over Her X-1 was performed at a rate of 0.02° sec^{-1}. The ACS positioned the payload axis too close to the source at the beginning of this scan so the source was already in the field of view of detector 3, as indicated by the high counting rate at about 175 sec. As the scan proceeds, the image of Her X-1 moves successively into detectors 2 and 1 as indicated by the sequential increase in counting rates registered by these detectors. Data in detector 2 is particularly noisy between $\sim$ 200 and 250 sec, however PCM data confirms the increased counting rate in detector 2 near 190 sec as being a real signal from Her X-1. The counting rate in the collimated detector is modulated very little throughout this period because of its relatively broad field of view (2° FWHM) compared to the apparent motion of the source during the scan from -0.5° to $+ 0.5^{\circ}$ relative to the payload axis. Also, because of the broad collimation, Her X-1 remains in the field of view of this detector during a roll maneuver at the end of this slow scan.

A scan of 1.6° was performed over the Virgo x-ray source, again at a rate of 0.02° sec^{-1}, but in the opposite sense to that over Her X-1. Consequently, this source appears in the three mirror detectors in the opposite sense, with the counting rates peaking at times of approximately 270, 280 and 295 sec in detectors 1, 2 and 3 respectively. Details of the source extent and its angular structure must await further analysis. A substantial decrease in counting rate occurs in the collimated detector throughout this scan since the apparent source motion proceeds from approximately 0° to 1.6° relative to the payload axis.

During the maneuver to ϵ and α Aur the payload axis passed sufficiently near the crab nebula to be observed by the collimated detector but appears in the mirror detectors only as a slight increase in counting rate by way of scattering off the reflectors. Two scans in opposite sense, 6° in length and at a rate of $\sim .15^{\circ}$ sec^{-1} were made over ϵ and α Aur. No signal is apparent from these objects in the preliminary data of Figure 2. The stars α Leo, ζ Her and ϵ Vir were in the field of view of detector 1 near times of 125, 158, and 245 sec. Again, no signal is apparent at these times in this preliminary reduction of data. Final analysis will decrease the noise level somewhat and if no signal is detected, allow at least upper limits to be placed on x-ray emission from these objects.

Preliminary reduction of data from the collimated detector has been completed for the observation of Her X-1. Figure 3 shows a preliminary light curve for this source in two energy intervals where the data have been folded with the period 1.24 sec. Modulation of the x-ray emission at this pulsation period is apparent and appears to diminish somewhat at low energy.

Film from the 35 mm camera, which photographed the star field, has been developed and is of high quality. Reduction of these photographs will provide the necessary aspect information for analysis of the flight data.

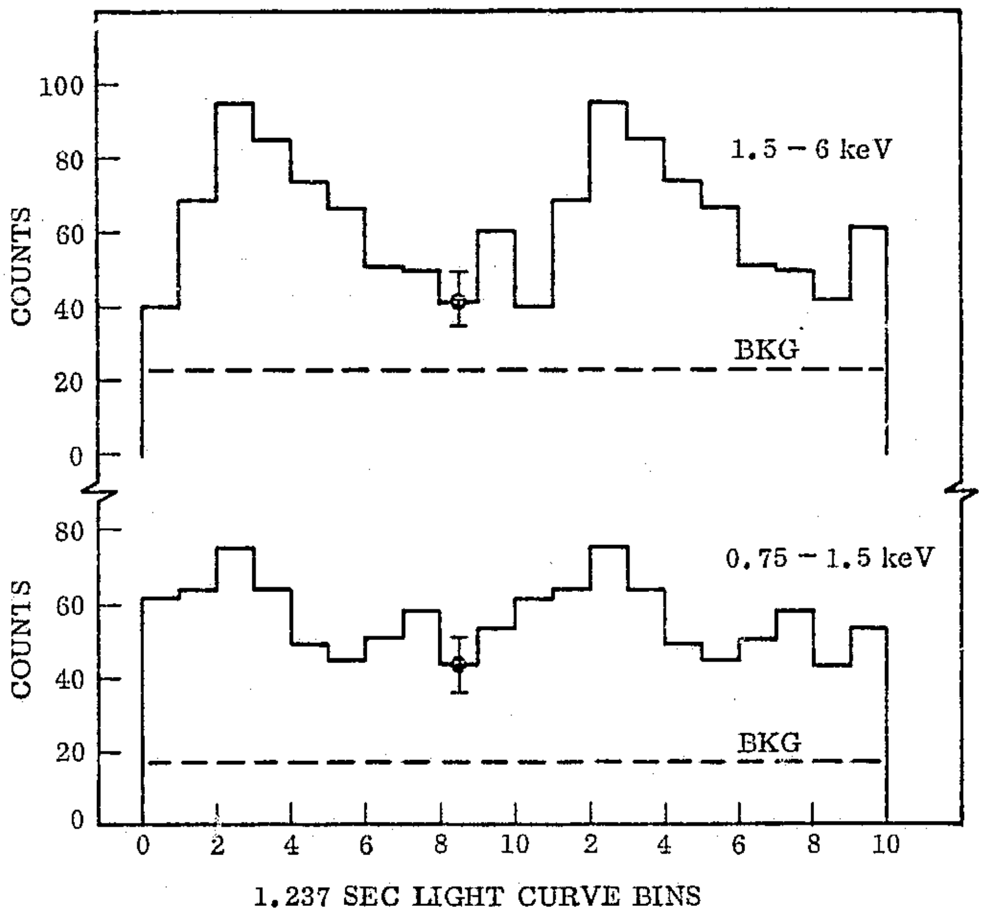


Figure 3 X-ray light curves of Her X-1

CONCLUSIONS AND RECOMMENDATIONS

A) X-ray reflectors that are built in the future should focus in both dimensions to produce an image of an x-ray source. While singly focussing optics have some advantage over collimated proportional counters, they suffer from the fact that in acquiring data their field of view must be scanned over a source. This is very inefficient for measurements with good angular resolution since only a small fraction of the observation time is spent collecting data from a given part of the source. Even the modest improvement in observing time obtained on this flight by increasing the angular aperture of the detectors at the reflector focus has proven to be very beneficial. Imaging optics, however, can acquire data with high resolution from each part of an extended source region for the full observing time.

B) Reliability of gas flow systems and thin polypropylene detector windows operating at atmospheric pressures have been established on this flight and on other solar rocket flights. The simplicity and low cost of these systems are of distinct advantage and their use is recommended. Also, there is no danger of applying high voltage destructively to the detector while it is accidentally evacuated, as there is in the case of sub-atmospheric counters utilizing flow into a vacuum system.